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PRECISION NAVIGATIONAL FILMSTRIPS FOR USE IN DOD  
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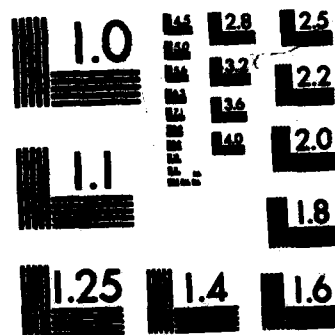
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The Defense Mapping Agency Aerospace Center (DMAAC) has been producing high resolution precision aircraft navigation filmstrips since 1967. These filmstrips are used in various type projection systems within Department of Defense (DoD) aircraft to provide the pilot/flight crew with a screen display of position and progress relative to the real world in real time. Superimposed on the projected chart image is an aircraft position symbol that appears to move across the display screen in the direction and at a speed proportionate to that being flown over the ground. DMAAC has produced numerous filmstrips for several operational

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**PRECISION NAVIGATIONAL FILMSTRIPS**

**FOR USE IN  
DOD AIRCRAFT**

**ROBERT BOZICH  
Lieutenant Commander, U.S. Navy  
Defense Mapping Agency  
Aerospace Center**

**September 1982**

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## ABSTRACT

The Defense Mapping Agency (DMA) has been producing high resolution precision aircraft navigation filmstrips since 1969. These filmstrips are used in various type projection systems within Department of Defense (DoD) aircraft to provide the pilot/flight crew with a screen display of position and progress relative to the real world in real time. Superimposed on the projected chart image is an aircraft position symbol that appears to move across the display screen in the direction and at a speed proportionate to that being flown over the ground. DMA has produced numerous filmstrips for several operational aircraft today and is currently producing filmstrips for test and evaluation in new aircraft systems which will require support well into the 1980s.

## BACKGROUND

In 1969 the Defense Mapping Agency Aerospace Center (DMAAC), formerly the Aeronautical Chart and Information Center (ACIC), was designated by the Defense Intelligence Agency (DIA) as the DoD filmstrip production agency. The initial requirement for aircraft navigational filmstrips came from the U.S. Navy in 1969. The filmstrips were to be utilized in the Projected Map Display System (PMDS) of the A-7E Aircraft. Shortly thereafter, the U.S. Air Force submitted a requirement for navigational filmstrips for the A-7D Aircraft and in 1970 the Air Force submitted additional requirements for navigational filmstrips for the Strategic Air Command (SAC) and the Tactical Air Command (TAC) F-111 aircraft. These two programs launched ACIC/DMAAC into production to meet military requirements. Initial operational filmstrips were delivered to the Navy in 1970. Since that time DMA has produced 34 operational A-7 filmstrips, 17 operational F-111 filmstrips, 13 operational HH-53 filmstrips, as well as numerous test filmstrips for Air Force and Army helicopter programs. All filmstrip production takes place at the Aerospace Center in St. Louis, Missouri. Considerable cartographic, photographic and production expertise was required to solve the many complex problems involved in filmstrip production. The production of a navigational filmstrip involves more than just taking a picture of an aeronautical chart. Because of the increased resolution demanded by the new filmstrip products, DMA's on-hand photographic equipment had to be dramatically upgraded to accommodate this new requirement. Two entire camera systems, that strained the state-of-the art technology at that time, were designed by the LATADY Instrument Company specifically to meet these needs. Today thirteen years later, these two cameras are still able to meet all resolution and accuracy requirements necessary to meet all known filmstrip requirements.

## FILMSTRIP CHARACTERISTICS

The Projected Map Display System (PMDS) in the A-7 aircraft, manufactured by Computing Devices Company of Canada, uses aircraft mission computer processed inertial navigation system output data to furnish a continuous real time display of the aircraft's geographic position. The DMA produced 35mm color filmstrip is the source of map imagery that is projected onto a 5" diameter ground glass high-gain (500%) screen. This system utilizes filmstrips produced from 1:500,000 scale Tactical Pilotage Charts (TPC) and 1:2,000,000 scale Jet Navigation Charts (JNC). A typical strip averages 37 feet in length portraying an area approximately 800 x 1000nm at TPC scale and 1600 x 2600nm at JNC scale. The filmstrip contains approximately 200 frames with a filmstrip chart scale reduced 12.053 times. See Figure 1 for chart scale relationships. The PMDS optics system projects the imagery onto the screen at a 16 times enlargement, thus producing a projected image scale 1.33 times the original source chart scale. The Army and the Air Force helicopter systems incorporate PMDS' similar to the A-7 but due to different

mission requirements, the scales of the source charts are different. The HH-53 helicopter system utilizes 1:250,000 scale Joint Operations Graphics (JOG) and 1:1,000,000 scale Operational Navigation Charts (ONC), while the AAH system will utilize 1:50,000 scale Topographic maps and 1:250,000 scale JOGs. The F/A-18 system, although somewhat different in the method of projection, will utilize the same basic source charts as the A-7. The A-10 system, still undetermined as far as area requirements are concerned, will utilize a Horizontal Situation Display (HSD) projection with chart scale similar to the HH-53.

The F-111 aircraft has an advanced avionics system which incorporates an HSD for projected map imagery. As with the A-7 system, the HSD system uses computer processed inertial navigation system output data to drive the filmstrip not onto a projection screen but electronically onto a Cathode Ray Tube (CRT). An inherent component of the HSD is the DMA produced 150mm (6") color filmstrip containing individual chart images. The chart image is electronically projected onto the face of a CRT which has a specially coated face plate for improving readability in a brightly lighted environment. The F-111 system filmstrips incorporate navigation charts at scales varying from 1:5,000,000 to 1:500,000. The 20 foot filmstrip contains 50 individual map frames at a 1:7.143 reduction factor for ONC and TPC charts and a 1:10.0 reduction factor for the JNC and Global Navigation and Planning Charts (GNC). In the HSD, the imagery is projected at a 10 times enlargement. The 7.143X reduction factor, resulting in a 1.4X enlargement of the source chart image on the display scope, provides the pilot less area coverage but compliments it with improved readability at low altitudes while the 10X reduction factor is normally used for extensive coverage in high altitude flight. See Figure 2 for a further breakdown of film size, display size and systems nomenclature used in the various types of aircraft.

Typically, the distance from the pilot's eye to the display screen is 30 inches. With hand-held paper charts, the pilot would normally hold the product only 18" to 20" away from his eyes. The overall resultant 1.33X enlargement of base chart information at the display screen viewed at 30", allows the pilot to see details at the same relative size as the original chart scale when viewed from 20".

### PRODUCTION PROCESSES

The following discussion on production processes and techniques will be oriented toward 35mm filmstrip production. Understand that the procedures associated with the 150mm filmstrips are quite similar.

The production process is subdivided into three prime areas:

- Generation of master projections.
- Paneling lithographic copies of the charts to the projections.
- Photographing panels onto high resolution color film.

The end result is to ensure compatibility between the computer software that drives the aircraft map display and the chart/frame relationship on the filmstrip.

The first step in producing a filmstrip is to generate a projection compatible with the electronic outputs of the specified aircraft inertial navigation system software. For example, the A-7 system uses a Lambert Conformal Projection, whereas the Army helicopter system uses an Azimuthal Equidistant Projection. The type projection



specified is that which is best suited for the aircraft's mission. Specifications call for varying formats which define the geographical orientation of coverage for the various chart scales. The formats have either a predominant North-South orientation or a predominant East-West orientation. See Figure 3. Also specified for the A-7/HH-53 filmstrips, is a reference point referred to as the LO/LaL which is defined as the intersection of the central meridian (LO) and the lowest usable latitude (LaL) for the format selected. The LO/LaL ties the generated frame matrix to the projection. The frame matrix is defined by the number of frames east-west and the number of rows north-south. As an example, the HH-53 ONC A-1 format has a frame matrix of 1 frame east-west and 25 rows north-south. See Figure 4. Other inputs for projection generation are the frame dimensions at the filmstrip scale, spheroid values, compilation scale and standard parallels for the projections. Based on these inputs, the DMAAC computer software generates a projection superimposed on the frame matrix for the geographical area defined. The data are stored on magnetic tape which in turn drives an automatic plotter. The projection and matrix are plotted on stable base polyester mylar (.007" thick) in a 13 x 41 inch frame format. Each projection called a "chunk", is plotted 3 frames high. See Figure 5.

The next production process, paneling the lithographic charts to the projection "chunks", constitutes the major portion of the filmstrip compilation. It is necessary to panel the lithos because of shrinkage in the non-stable paper used in printing, the frame matrix does not correspond to chart area, and the lithos have been produced using different projections and standard parallels. The paneling, which involves cutting the lithos into various size pieces and then fitting these pieces to the projection, is accomplished to a .002 inch tolerance. The paneling may be thought of as either a "shrinking" or "stretching" of the lithos to fit the projection. The number of cuts required depends upon the amount of "shrinking" or "stretching" required to maintain the .002 inch tolerance between the master projection and the chart projection lines. The cuts also distribute errors over a large area so that no gaps show between separate litho pieces. The litho pieces are panelled to the projection using wax as an adhesive which allows a piece to be placed in its approximate position and eased into its exact location with little effort. Figure 1 generally outlines the frame formats giving base chart information, chart scale, film scale and area coverage.

In chart water areas of white or very light blue, colored translucent film (blue zip-a-tone) is applied to reduce the light projected on the screen in the display system. Source material for total filmstrip coverage of the airfield area may not exist or may be incomplete. Green zip-a-tone is used where chart coverage does not exist and yellow zip-a-tone is used where relief data is incomplete. Each chart used in the filmstrip is updated to include information potentially hazardous to low level flight. Of major concern are obstructions (towers, powerlines, and similar features) and significant cultural features, that did not exist or were not known to exist when the chart was produced. Various overlays are photographed onto each frame which indicate the outer edge of filmstrip coverage, shift zones, hysteresis zones and the useful area of coverage for each frame. All compilation and photographic source materials will be pre-punched using a precise registration to ensure that registration of all materials is maintained throughout the entire photographic reduction process.

The final phase in the production process is the precise sequential photographing of the frame panels onto the film base. The film resolution, color densities and frame positioning are extremely critical. A LATADY 70mm precision reduction camera with a nominal reduction factor of 12.053 is dedicated for all 35mm filmstrip work. The camera, with a Micro-NIKKON Lens, is a stock item. A specially built camera back, manufactured by Computing Devices Company, is used for precision film advance. The camera back can

accommodate 180 feet of 35mm film and is capable of advancing film to an accuracy of  $\pm .0005$  inch. The film is advanced manually based on settings computed by empirical testing. The exact center of the filmstrip, designated the "A-Frame" is the reference point from which all other measurements on the filmstrip are made. The setting for the "A-Frame" is determined and from this measured number a constant (22708.65), which corresponds to exactly 3.390 inches of film (2 frames), is added or subtracted to obtain settings for each exposure. The exposures are butt joined with a .002 inch maximum overlap. Each exposure, corresponding to a double aperture exposure, covers one 13 x 41 inch panel containing two filmstrip map frames. Because the aircraft system "thinks" in terms of map inches, the placement of map frames on the filmstrip is extremely critical. Also, frame placement relative to the film sprocket holes must be maintained to very close tolerances. Precise alignment between the panels and camera frame is required to accomplish accurate positioning; a three pin registration system, a vacuum frame, a master alignment grid, and a series of reference marks are used. Each frame alignment is precisely checked on a comparator machine capable of measuring frame locations to within .0005".

The film used is a very high resolution, high contrast, color reversal, Eastman Kodak 35mm color film capable of 200 line pairs/mm resolution. See Figure 6 for film specifications. Color densities are controlled ( $\pm .05$ ) by use of a 50% gray scale reflectance card and readouts on a densitometer using Status A-type filters. The light source is filtered at the copy board in order to maintain maximum possible resolution and color balance.

Both the 35mm and the 150mm film master strips are developed (processed) on a KODAK 1811 Color Ektachrome Processor. A Bell and Howell color contact printer is used to produce the 35mm duplicate copies moving at the rate of 180 feet per minute in a continuous loop. A Miller-Holzworth step and repeat contact printer is used for the 150mm duplicates. Product specifications of 120 line pairs/mm for the master and 85 line pair/mm for the duplicates can easily be met using these two types of printers.

For the F-111 filmstrips, a universal LATADY camera with a GOERZ lens (focal length - 12", f - 6.3) capable of 200 line pairs/mm resolution is used. This system incorporates a Miller Holzworth 6" camera back capable of single frame manual advance utilizing a Geneva movement drive system. Nominal reduction factors of 7X and 10X are utilized in F-111 filmstrips. The frames are not butt joined but appear as separate frames in the filmstrip. The center sprocket hole of each frame is the reference point for positioning.

A maintenance/revision cycle has been incorporated so as to effect a completely new product, at the most, every three years for the 35mm filmstrips and every two years for the 150mm filmstrips. Another prerequisite must be met before a new filmstrip is produced. Whenever fifty percent of the base charts for the 35mm strips or twenty-five percent for the 150mm strips have become outdated by printing of new editions, a new strip is produced. When an outdated strip is due for revision, only the charts that have been changed are replaced on the new edition, thereby reducing greatly the total manhours required in producing a completely new filmstrip. The same product specifications apply to revised editions as to the original master strip.

DMA is currently in the process of procuring a universal filmstrip generator capable of handling film widths from 35mm to 150mm. This reduction copy camera system, being specially manufactured for DMA, will utilize an HLC Dekacon III Camera System or equivalent with a universal roll film back. The camera back will be capable of handling both perforated and non-perforated film. The camera optical axis orthogonality and the copy/film plane parallelism will be maintained to within  $\pm .0005$  inches for a continuous

range of settings from 7X through 15X reductions. The lens system will have an aerial resolving power of 230 line pairs/mm.

Due to the complex nature of many of the new aircraft weapons systems, the onboard mission computer is being overtaxed and is approaching its maximum capabilities. The recent incorporation of a Read Only Memory (ROM) module will greatly reduce the storage capacity required for navigational filmstrips. Until now, individual filmstrip parameters and data had to be hand loaded, up to 350 individual key punches, into the computer and stored in its memory every time a filmstrip was changed or replaced. If aircraft power was lost or disrupted, the same data load sequence had to be followed. With the use of the ROM, having been previously programmed with the filmstrip parameters, it can be plugged into a receptacle hardwired to the computer and not use valuable computer storage space. No computer programming, and minimum data load key punches will be required in the field since the ROM comes already programmed with each individual filmstrip. Currently only the A-10 and A-18 display systems anticipate using ROMs. However, it is expected that all future aircraft navigation displays of this type will be incorporating the ROM or some other version of firmware such as the programming of filmstrip data parameters directly onto the Operational Flight Program (OFP). With the state-of-the-art technology constantly increasing the storage capacity of many on-board computer systems, incorporation of the filmstrip parameters directly into the OFP is a definite possibility.

#### CONCLUSION

The navigational filmstrips produced by DMA have been enthusiastically received by all users in the Department of Defense. They have proven so successful in various aircraft and all types of operational as well as training missions, that high resolution precision navigational filmstrip systems have become an integral part of many aircraft display systems. DMA has rapidly progressed from a maintenance only posture with the A-7 and F-111 to a highly paced production schedule with the HH-53 and F/A-18 and shortly with the AH-64 and A-10. Based on current known operational requirements, production of aircraft precision navigational filmstrips will continue well into the late 1980's. New systems such as the A-10 and the Army AH-64 are in the planning stages and will be submitting requirements shortly. Advanced systems such as the F-15, LHX, HX, MC-130E, CH-53E, MH-53E and various other close support type aircraft have indicated interests in some type of map display system. If any of these systems become operational, and the likelihood is very great that they all will, then DMA will be in the filmstrip making business well into the 1990's.

<u>FORMAT</u>	<u>AREA</u>	<u>FILM SCALE</u>	<u>CHART SCALE</u>	<u>DISPLAY SCALE</u>	<u>CHART MEASURE</u>		<u>CHART AREA</u>	<u>CHART SERIES</u>
					<u>N/S</u>	<u>E/W</u>	<u>N/S</u>	<u>E/W</u>
A-1 (N/S)	Local	1:3,013,325	1:250,000	1:188,333	16.568"	10.170"	672	407 JOG
A-1 (N/S)	Local	1:6,026,650	1:500,000	1:376,665	12.025"	10.170"	995	840 TPC
B-1 (N/S)	Local	1:12,053,300	1:1,000,000	1:753,330	4.400"	3.390"	676	509 ONC
B-1 (N/S)	Local	1:24,106,600	1:2,000,000	1:1,506,660	3.272"	3.390"	1080	1120 JNC
A-2 (E/W)	Local	1:3,013,325	1:250,000	1:188,333	9.429"	16.950"	377	688 JOG
A-2 (E/W)	Local	1:6,026,650	1:500,000	1:376,665	10.078"	13.560"	835	1120 TPC
B-2 (E/W)	Local	1:12,053,300	1:1,000,000	1:753,330	2.615"	6.780"	381	1069 ONC
B-2 (E/W)	Local	1:24,106,600	1:2,000,000	1:1,506,660	2.780"	3.390"	920	1120 JNC
B-1 (N/S)	General	1:12,053,300	1:1,000,000	1:753,330	9.687"	5.085"	1550	789 ONC
B-1 (N/S)	General	1:24,106,600	1:2,000,000	1:1,506,660	7.652"	5.085"	2530	1680 JNC
B-2 (E/W)	General	1:12,053,300	1:1,000,000	1:753,330	5.015"	10.170"	777	1680 ONC
B-2 (E/W)	General	1:24,106,600	1:2,000,000	1:1,506,660	4.988"	8.475"	1650	2880 JNC

**NOTES:**

- A - Defines local area coverage
- B - Defines general area coverage (also local area immediately surrounding A coverage)
- 1 - Predominantly North - South orientation
- 2 - Predominantly East - West orientation

Figure 1. Typical Format Description, Dimension and Coverage for the A-7 and HH-53 Aircraft

<u>Type Aircraft</u>	<u>Film Size</u>	<u>Display</u>	<u>Nomenclature</u>	<u># of Filmstrips</u>
A-7E (USN)	35 mm	5"	ASN-99/PMS-4	34 (same as A-7D)
A-7D (USAF)	35 mm	5"	ASN-99/PMS-4	34 (same as A-7E)
F-111 (USAF)	150 mm	6.5"	P/N 110150	17
HH-53 (USAF)	35 mm	5"	ASN-99/PMS-4	13
AAH (USA)	35 mm	5"	ASN-99/PMS-4	Undetermined
A-10 (USAF)	70 or 150 mm	4"x4"	Undetermined	Undetermined
A-18 (USN)	35 mm	5.5"x7"	IP-1350/A HI	Undetermined

**Figure 2. Precision Aircraft Navigational Filmstrips  
Hardware Characteristics.**

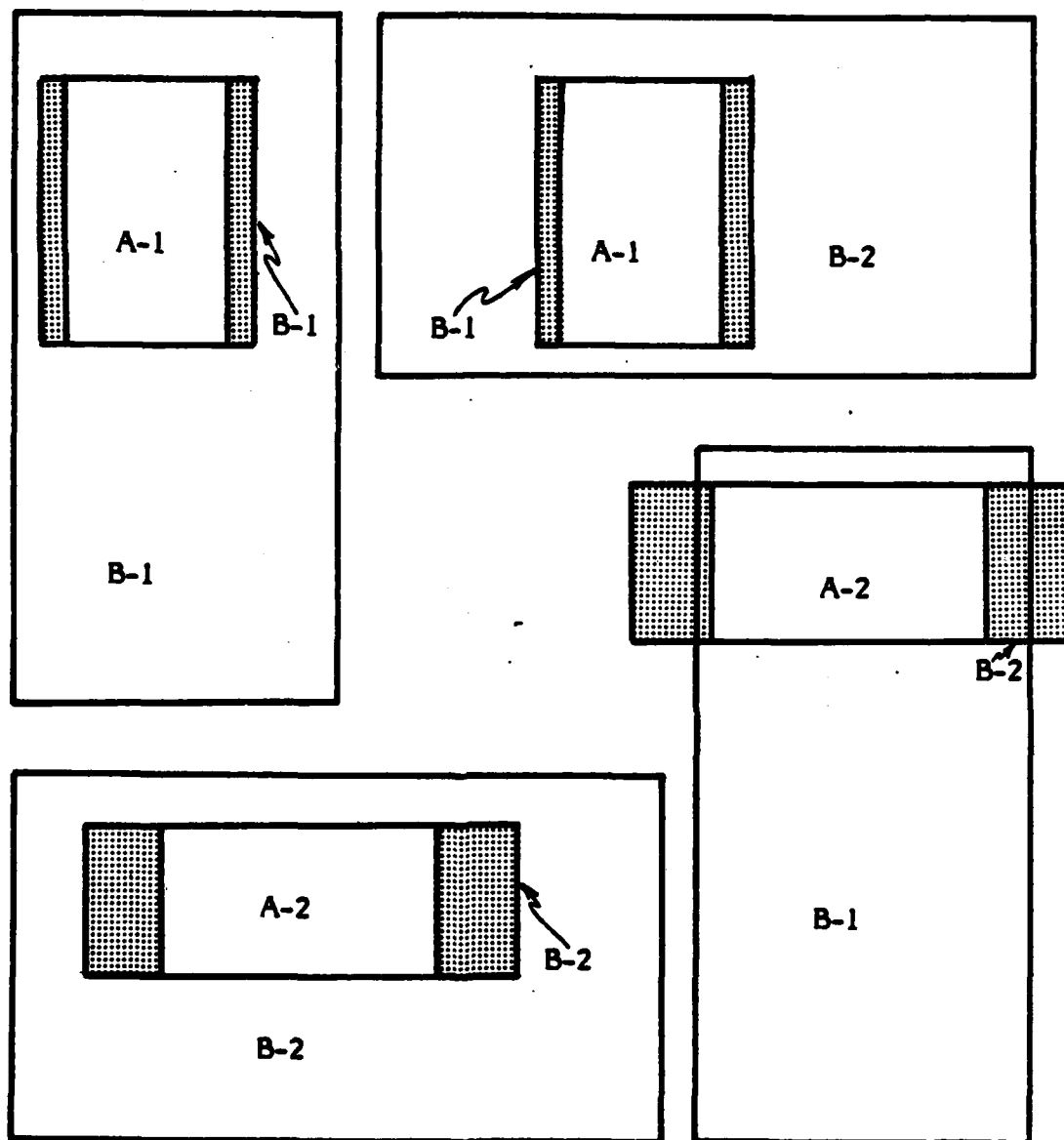


Figure 3. Geographic Area Relationships for Typical "A" and "B" Formats.

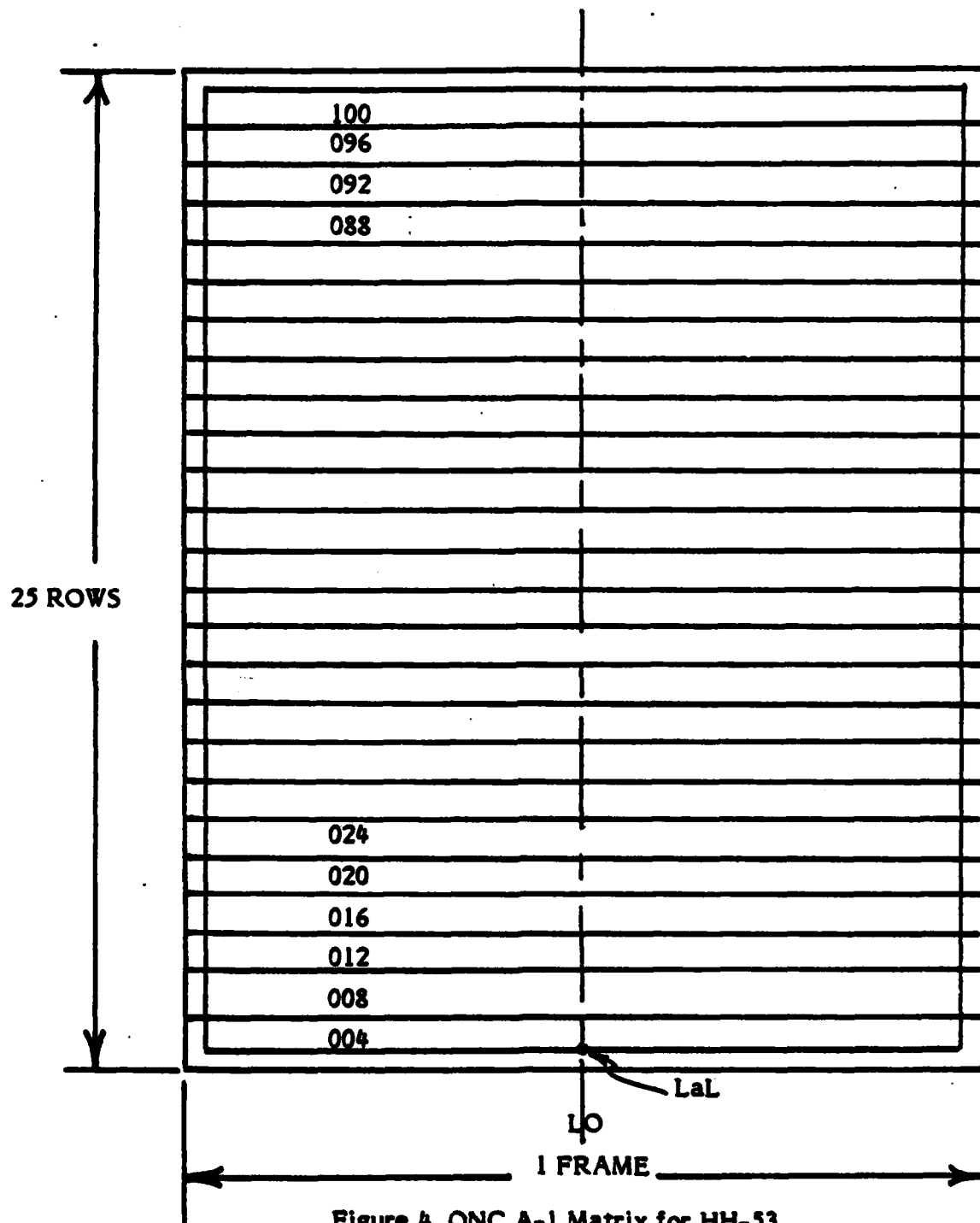


Figure 4. ONC A-1 Matrix for HH-53

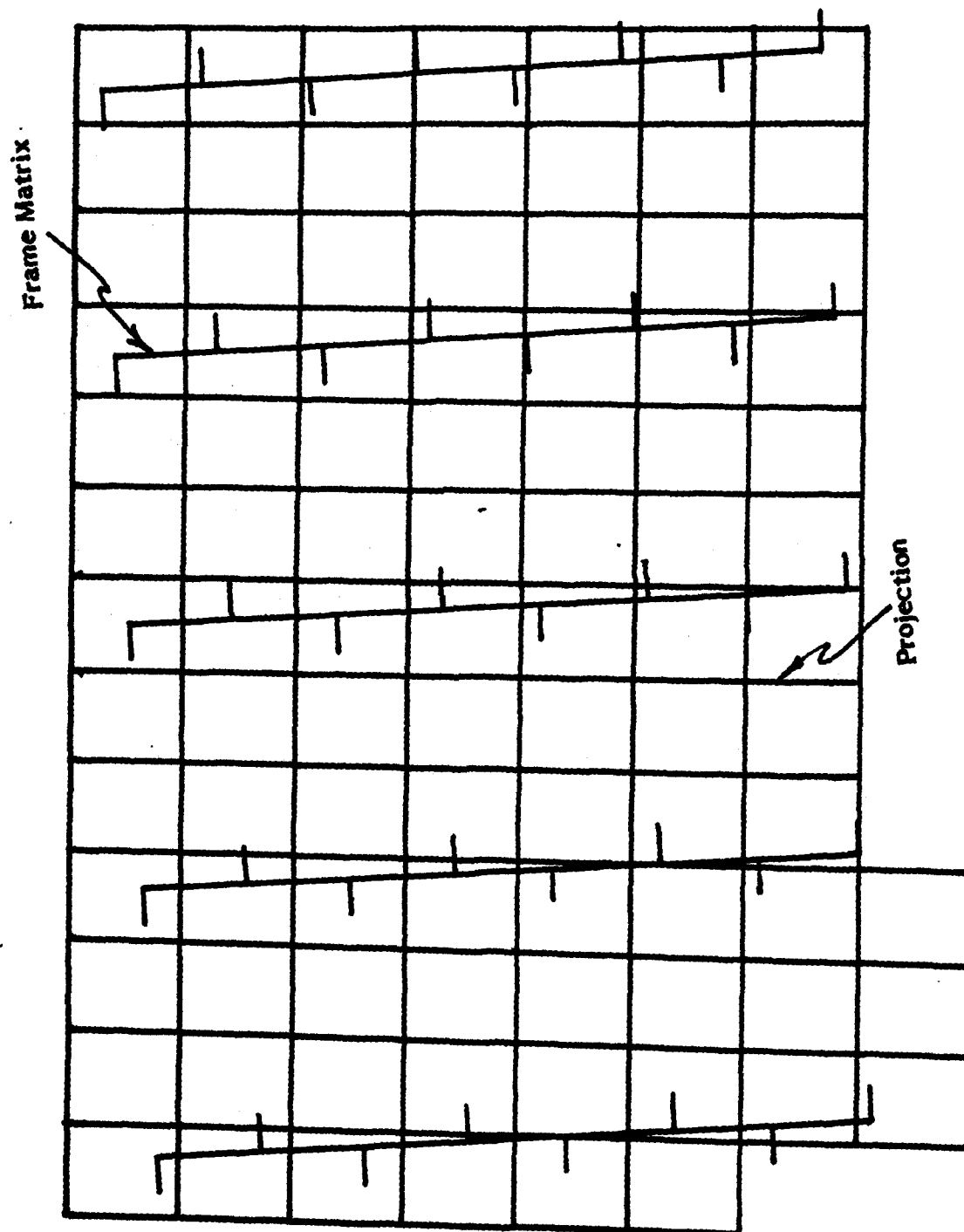
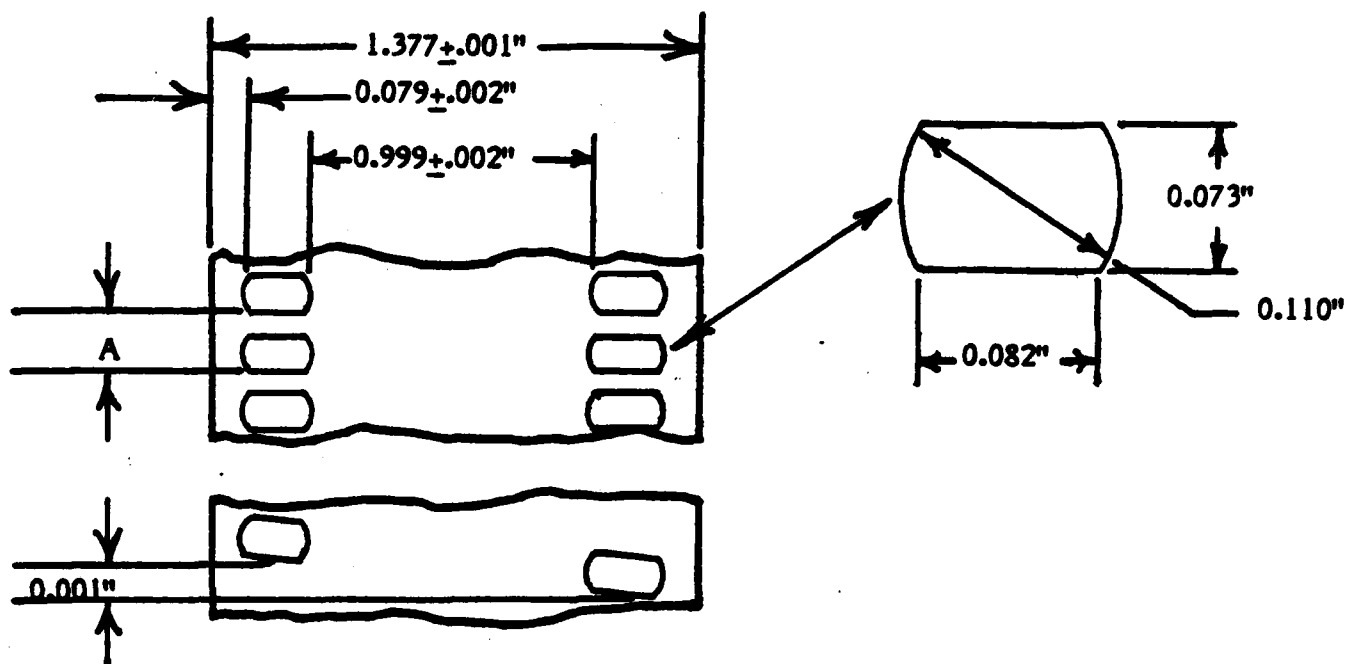


Figure 5. Projection "chunk".





Bell and Howell Perforation Tolerances  $\pm .0002''$ .

Dimension	BH-1866		BH-1870		Tolerance	
	Inch	mm	Inch	mm	Inch	mm
A	0.1866	4.74	0.1870	4.75	0.0005	0.013
L*	18.66	474.00	18.70	475.00	0.015	0.38

\*This dimension represents the length of any 100 consecutive perforation intervals.

Figure 6. Filmstrip Perforations and Dimensions

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